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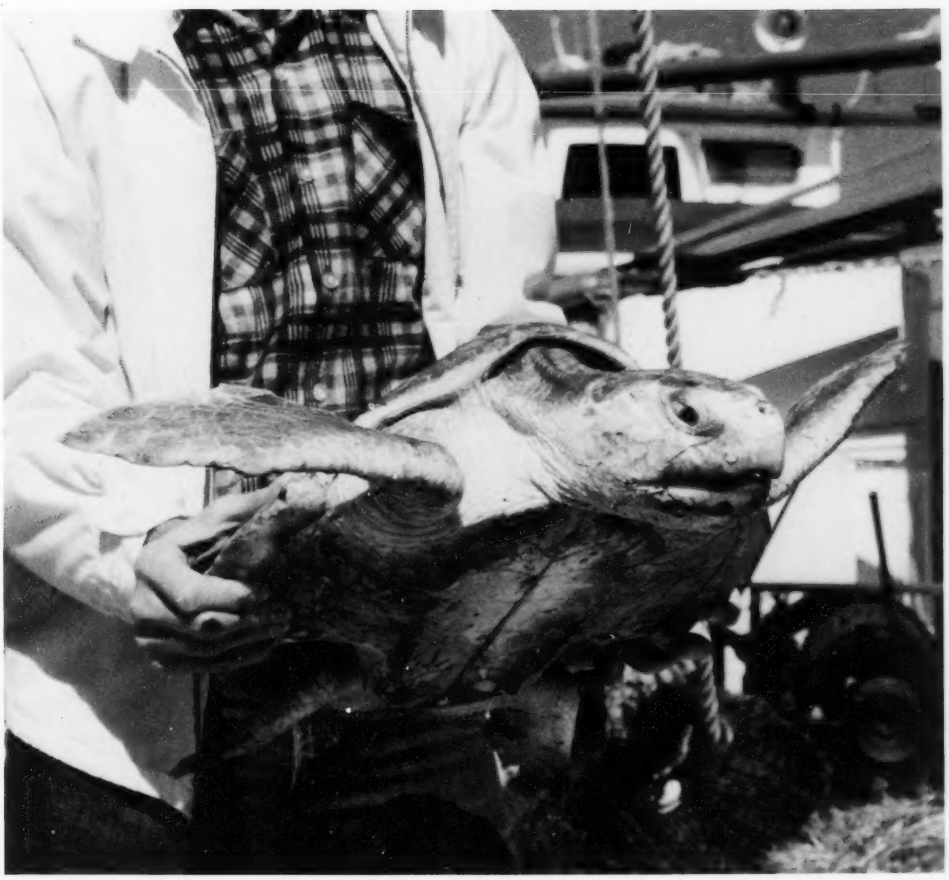

SEA TURTLES

Marine Fisheries REVIEW

On the cover: A Kemp's ridley sea turtle. NMFS photograph by Larry Ogren.

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Biology and Fishery for Atlantic Thread Herring, *Opisthonema oglinum*, along the North Carolina Coast

JOSEPH W. SMITH

Introduction

Thread herrings, *Opisthonema* spp., are small, nearshore, pelagic clupeid fishes that form dense, surface schools in tropical to subtropical coastal waters. Ecologically, thread herrings form an important forage base for many large, predatory fishes (Finucane and Vaught, 1986). Commercially, thread herrings are targeted by artisanal to moderate-sized seine fisheries off the coasts of Ecuador and Peru (Patterson and Santos, 1992), Costa Rica (Stevenson and Carranza, 1981), Venezuela, the continental margins of the Caribbean, the Gulf of Mexico, and near the islands of Cuba, Hispaniola, Puerto Rico, Jamaica, and Trinidad (Reintjes, 1978). Most of the catch is reduced to fish meal and fish oil (Patterson and Santos, 1992), although minor quantities are used for human consumption (Reintjes, 1978).

Along the northern Gulf of Mexico and southeastern Atlantic coasts of the United States, the Atlantic thread herring, *O. oglinum* (Fig. 1), is mainly harvested with purse seines. Directed fisheries for Atlantic thread herring (and other coastal herrings) in the northern Gulf of Mexico are concentrated along the northwestern coast of Florida where most of the catch is sold as bait or processed into pet food (Finucane and Vaught, 1986). Purse seine vessels of the Gulf menhaden, *Brevoortia patronus*, reduction fishery, centered off the coasts of Mississippi and Louisiana (Smith, 1991), catch minor quantities of *O. oglinum* during the summer while searching for Gulf menhaden (Reintjes, 1980). Studies in the Gulf report that Atlantic thread herring prefer "bluer" water, higher salinities, and higher water temperatures than menhaden (Finucane and Vaught, 1986). Additionally, schools of Atlantic thread herring are exceptionally fast and agile (Butler, 1961) and are more difficult to catch in purse seines than menhaden (Kinnear and Fuss, 1971).

On the U.S. east coast, Atlantic thread herring range from Florida to Cape Cod (Bigelow and Schroeder, 1953; Robins et al., 1986), although they are "not numerous" north of North Carolina (Hildebrand, 1963). During summer along the southeastern U.S. Atlantic coast, they are distributed ubiquitously in coastal waters from North Carolina to northern Florida to depths of about 9 m, while they concentrate off Georgia and north Florida during spring, fall, and winter (Wenner and Sedberry, 1989). Although small amounts of Atlantic thread herring are harvested off the east coast of Florida for bait (USDOC, 1984; Smillie, 1994), at present, commercial landings of Atlantic thread herring for reduction to fish meal and fish oil are restricted to coastal waters between Cape Hatteras and Cape Fear, N.C., during late summer and fall (personal observ.).

Pristas and Cheek (1973) recognized the significance of these autumnal schools as a supplement to the extant Atlantic menhaden, *B. tyrannus*, reduction fishery (Smith, 1991), and devised a tagging study to determine the distribution and movement of *O. oglinum* off the U.S. southeastern Atlantic coast. Internal ferromagnetic tags were in-

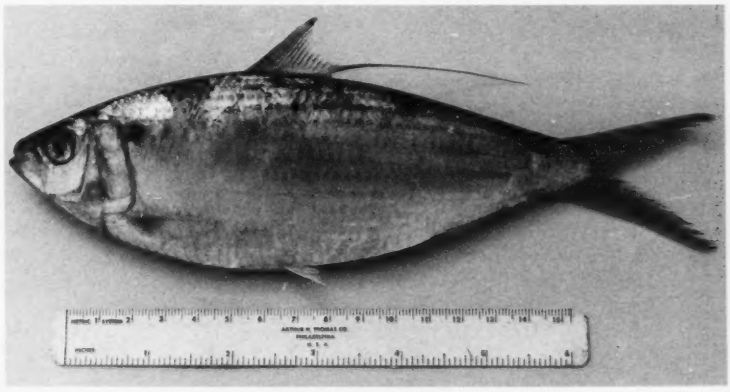

Figure 1. — Atlantic thread herring, *Opisthonema oglinum*.

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jected into nearly 1,600 Atlantic thread herring off the North Carolina coast. Tag recoveries (from magnets at menhaden reduction facilities in North Carolina and Florida) indicated that schools of *O. oglinum* migrate south along the southeastern U.S. Atlantic coast during fall at up to 11 km per day.

The Atlantic thread herring resource, especially the stock in the eastern Gulf of Mexico (Houde, 1976), has been extolled as a latent resource and an alternative to menhaden for a reduction fishery (Bullis and Carpenter, 1968). Pristas and Cheek (1973) estimated that the population size off the southeastern U.S. Atlantic coast could vary between 22,000 and 92,000 metric tons (t). Objectives of this study were to 1) describe the purse seine reduction fishery for Atlantic thread herring in North Carolina and 2) determine the size, age composition, and reproductive condition of the catch.

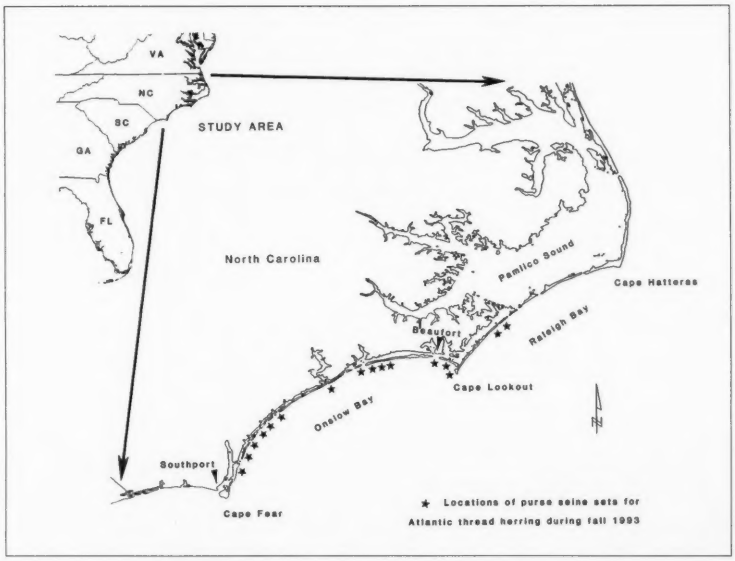

Figure 2. — Study area: Raleigh and Onslow bays, N.C. Stars indicate sites of purse seine sets for Atlantic thread herring, *O. oglinum*, during fall 1993; set locations exaggerated offshore for illustrative clarity.

Biology of the Atlantic Thread Herring

Sampling

Atlantic thread herring were collected from purse seine catches unloaded for reduction at Beaufort, N.C. (Fig. 2), between 1985 and 1990. Sampling routines for menhaden (Smith et al., 1987) were followed with minor adjustments. Briefly, a port agent acquired a bucket of fish from a purse seine vessel at dockside. Fish on top of the hold were assumed to be from the last purse seine set of the day. Date and location of the set were determined from a crew member.

At the laboratory, up to 50 Atlantic thread herring were randomly chosen from the bucket. Each fish was measured for total (TL), fork (FL), and standard (SL) length and weighed to the nearest gram; subsequent text references to length are fork lengths. From the first 25 fish measured, a patch of scales (from the midline below the dorsal fin) and the sagittal otoliths were removed and stored in labelled envelopes; each fish was sexed and macroscopically staged for maturity following Waltz et al. (1979). A few gonadal samples were prepared using standard histological techniques (Humason, 1972) to confirm gonad staging in the field. In 1988 juvenile Atlantic thread herring were collected with a cast net from the Newport River estuary, about 4 km from Beaufort Inlet (Fig. 2); these fish were processed similar to the purse seine samples.

Seasonality and Age/Size Composition

Twenty-one biological samples were collected from purse seine sets that directly targeted schools of Atlantic thread herring. A total of 12 samples were acquired in September (n=473 fish), 7 samples in October (n=175), and one each in June (n=50) and July (n=50). Specimens ranged from 125 to 200 mm and from 30 to 140 g. Length-length and length-weight relationships are shown in Table 1. Mean size of Atlantic thread herring in the samples increased across months sampled: 146 mm and 50 g in June, 154 mm and 62 g in July, 166 mm and 85 g in September, and 172 mm and 93 g in October. Specimens taken by cast nets near the laboratory from June through September ranged from 62 to 118 mm ($\bar{x}$ = 77 mm) and 3 to 27 g ($\bar{x}$ = 7 g). Juvenile Atlantic thread herring disappeared from this estuarine site by October.

Atlantic thread herring scales were projected on a macroprojector and were

Table 1.—Length-weight and length-length relationships (natural logs and functional regressions, Ricker, 1973) for Atlantic thread herring from North Carolina. *W* is weight in grams; FL, TL, and SL are fork, total, and standard lengths, respectively, in millimeters; I is immature fish; MSE is mean squared error.

Functional equation	Sex	No.	r^2	MSE	Size range (mm FL)
log *W* = -13.2 + 3.4 log FL	♂	179	0.93	0.0056	125–190
log *W* = -13.1 + 3.4 log FL	♀	297	0.94	0.0047	136–200
log *W* = -12.6 + 3.4 log FL	♂+♀+I	879	0.99	0.0068	62–200
TL = -0.5 + 1.2 FL	♂	179	0.98		125–190
TL = -3.9 + 1.2 FL	♀	297	0.98		136–200
TL = 4.0 + 1.2 FL	♂+♀+I	879	0.99		62–200
SL = 0.1 + 0.9 FL	♂	179	0.97		125–190
SL = -3.1 + 1.0 FL	♀	297	0.97		136–200
SL = -4.5 + 1.0 FL	♂+♀+I	879	0.97		62–200

scrutinized for annular rings using criteria developed for Atlantic menhaden (June and Roithmayr, 1960). Whole sagittal otoliths were embedded in black, opaque well plates (Pentilla et al., 1988) with a microscopy fixative and viewed under a dissecting macroscope with reflected light at 16× magnification (Fig. 3). Sagittae of Atlantic thread herring were nearly identical to sagittae of Atlantic herring, *Clupea harengus*, with narrow translucent zones adjacent wide opaque zones (Fig. 3), as documented in the latter species (Dery, 1988). I counted translucent zones in the posterior field of the sagitta as presumed annuli. Sagittae were "read" twice. Where discrepancies in the two readings occurred, the specimens were eliminated from further age analyses.

Mean fork length of Atlantic thread herring increased with increasing age estimates (Table 2); the oldest Atlantic thread herring was estimated at age 8. Modal age for the purse seine samples was age 1 (33.2%), followed by age 2 (30.4%) and age 3 (22.0%); 85.4% of the fish aged from purse seine samples were ages 1 to 3 (Fig. 4). Nearly all fish taken by cast net (91 of 92 fish, 98.9%) were young-of-year (age 0), except one specimen that was age 1. Paired age estimates, that is, otolith and scale ages, were only available for 46 specimens; 80.4% or 37 of 46 otolith:scale pairings were in agreement.

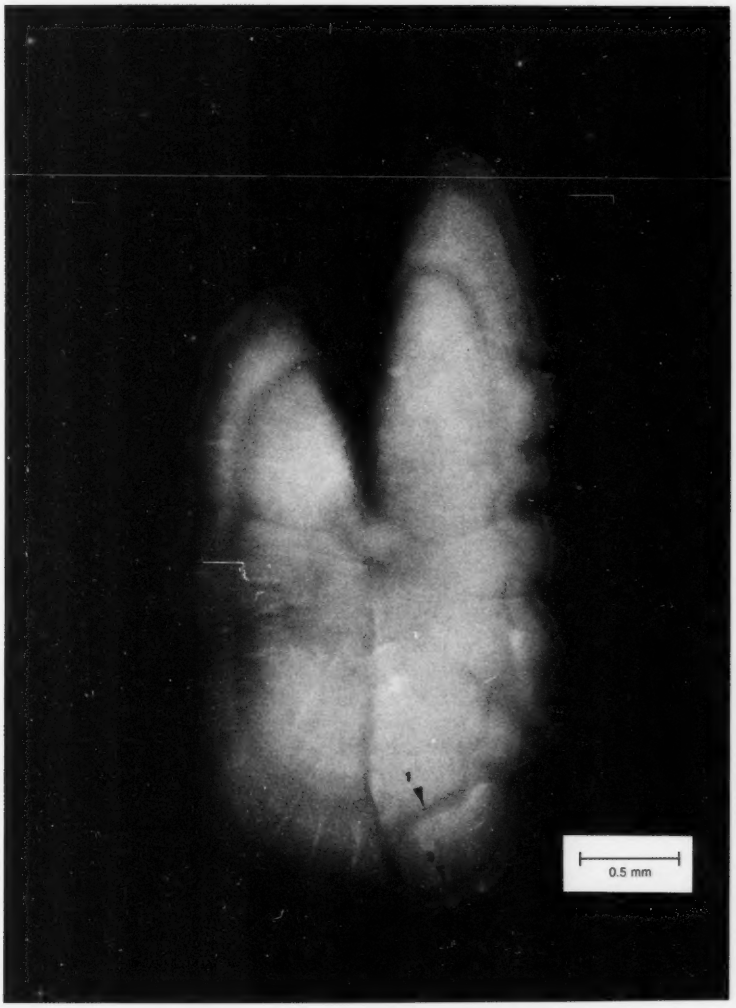

Figure 3. — Sagittal otolith from an Atlantic thread herring, age 2, 179 mm FL.

Reproduction

Paired determinations of sex using macroscopic and histologic observations agreed for 34 of 35 comparisons. The sex ratio of pooled purse seine samples was skewed toward females (♂ : ♀, 179:299). In June, 14 of 15 males from the purse seine sample were ripe. Also in June, ovaries from three females indicated recent spawning; post-ovulatory follicles were present with a large number of oocytes in various stages of atresia. Individuals of both sexes taken in September and October were staged as resting.

Description of the Fishery

In recent years Beaufort, N.C., has been the only port along the U.S. Atlantic coast where *O. oglinum* were harvested for reduction by a directed purse seine fishery. Locally the fish are called "hairy backs" because of the elongated last ray of the dorsal fin. Historical landings of Atlantic thread herring in North Carolina were often significant and occurred at a time when seasonal abundance of Atlantic menhaden during late summer had ebbed. During the 1960's and 1970's, reduction factories in Southport, N.C. (near Cape Fear), also processed Atlantic thread herring, but these plants closed by 1984. Landings of Atlantic thread herring for reduction in North Carolina since 1965 have fluctuated widely (Fig. 5), but averaged about 1.9 million kg annually between 1965 and 1994; record landings of 9.7 million kg occurred in 1972. Since 1986 only one reduction factory in Beaufort has operated, employing 2-3 purse seine vessels. Sparse landings during the late 1980's were attributable to low fish meal prices and consequently, reduced purse seining activity from the port of Beaufort.

In general, purse seine sets on Atlantic thread herring were made in the Atlantic Ocean within a few kilometers of

shore and in depths to 18 m between Cape Lookout and Cape Fear, N.C. From 1983 to 1993 most sets on Atlantic thread herring by vessels from Beaufort occurred between 2 September and 14 October. Two noteworthy sets occurred near Cape Hatteras, one in July 1986 and the other in June 1990.

Several aircraft spotter pilots and captains of purse seine vessels from North Carolina related that schools of Atlantic thread herring were rarely encountered during summer in the state's coastal waters (personal observ.). Occasionally, schools were sighted in the ocean along Virginia's Eastern Shore and in the vicinity of Cape Henry, Virginia, in late August. In general, large, fishable schools of Atlantic thread herring arrived in nearshore waters adjacent to Cape Lookout, N.C. (Fig. 2), in early September. Purse seine vessels from Beaufort harvested Atlantic thread herring during September, as the schools moved south and west along the coast toward Cape Fear, N.C. During most years, the purse seiners stopped pursuing the fish once they moved south of Cape Fear, which was usually by early to mid-October.

During September and October, catches of Atlantic thread herring supplement landings at the fish reduction plant in Beaufort at a time when the abundance of Atlantic menhaden in the vicinity has waned, and prior to the fall migration (mid to late October) of Atlantic menhaden from areas farther north (Smith et al., 1987). During fall, the visceral cavity of Atlantic thread herring is heavily lined with fat deposits. Accordingly, yields of fish oil from Atlantic thread herring in the fall are exceptional, averaging 9–10 U.S. gallons of fish oil per 670 pounds of fish (the menhaden industry's unit of measure; Smith, 1991), while yields of 15–16 gallons are common. By comparison, fish oil yields from Atlantic menhaden during late summer in the U.S. southeastern Atlantic average less than 2–3 U.S. gallons per 670 pounds of fish (personal observ.).

Menhaden vessel captains keep daily purse seining activity logs (Captain's Daily Fishing Reports, or CDFR's; Smith, 1991) that tabulate individual purse seine sets by location and distance from shore, and provide an at-sea estimate of the quantity of each purse seine catch. I examined CDFR's from two North Carolina vessels that logged data for sets on Atlantic thread herring during September and October 1993. I assumed that each purse seine set was made on only one school of Atlantic thread herring. Although captains are adept at judging the quantity of fish in each catch, individual at-sea catch estimates were adjusted slightly and converted to metric tons based on daily amounts offloaded at the fish plant (from company records). The mean weight of individual Atlantic thread herring in 1993 port samples was used to estimate numbers of fish caught per set.

CDFR data documented 48 successful purse seine sets on Atlantic thread herring schools by two North Carolina vessels between 28 September-14 October 1993. Sets were distributed from Core Banks near Cape Lookout to Wrightsville Beach near Cape Fear and from 0.4 to 2.4 km from shore (Fig. 2). Individual catch estimates ranged from 5.8 to 204.2 t, and the mean catch was 55.9 t. Mean weight of individual Atlantic thread herring in 1993 port samples was 85 g; thus, a school of av-

Table 2.—Mean size at estimated age for Atlantic thread herring from North Carolina. Values from the literature shown for comparison.

Est. age (yr)	Present Study[1] FL (mm) Mean	FL (mm) Range	Weight (g) Mean	Weight (g) No.	Houde et al. (1983)[1] mean FL (mm)	Fuss et al. (1969)[2] mean FL (mm)
0[3]	76	64–98	7	91		
1[4]	155	135–183	64	93	108.2	146
2	172	154–190	91	85	152.4	149
3	178	163–196	102	63	171.0	148
4	180	168–193	109	25	179.5	
5	183	171–190	114	8	186.8	
6	180	171–185	114	7	202.7	
7	186		108	1		
8	175		101	1		

[1] Aged using sagittal otoliths.
[2] Aged using scales.
[3] Specimens collected by cast net.
[4] Specimens age 1–8 collected from purse seines.

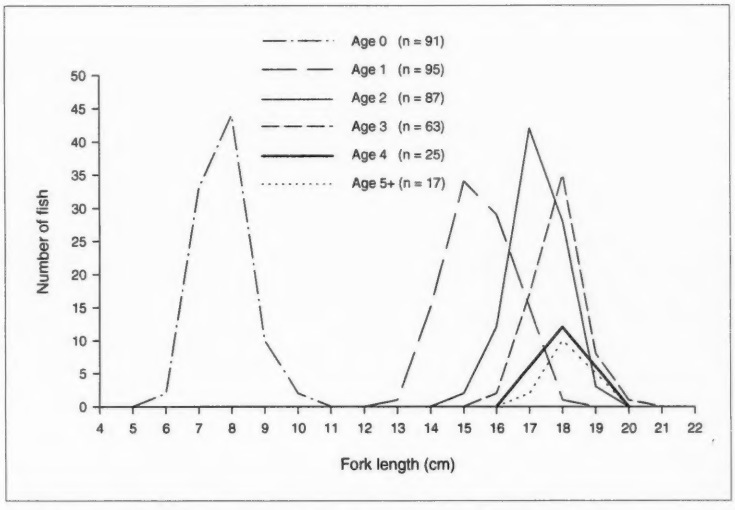

Figure 4. — Fork length frequency distributions of Atlantic thread herring by age from cast nets (age 0 fish) and purse seines (age 1–5+ fish).

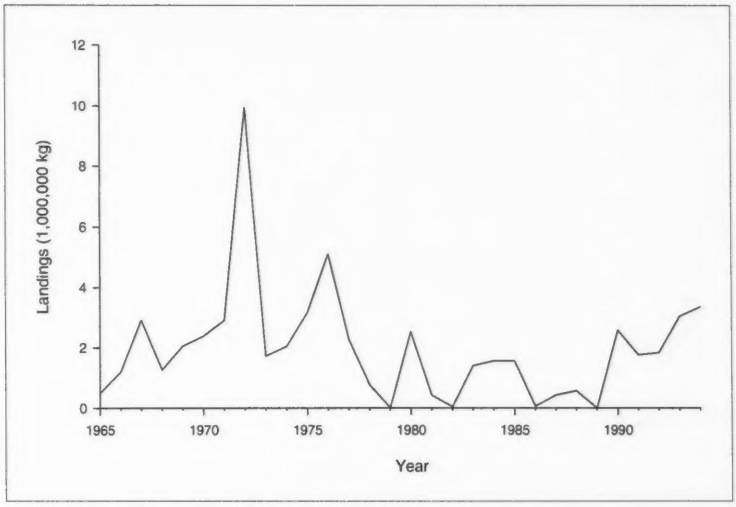

Figure 5. — Purse seine landings of Atlantic thread herring for reduction in North Carolina, 1965–94.

erage size was estimated to contain 657,650 fish, while extreme sets during 1993 were estimated to contain 68,250 to 2,402,350 fish.

Discussion

An autumnal migration of adult Atlantic thread herring along the southeastern U.S Atlantic coast begins in the nearshore ocean waters of Raleigh and Onslow bays in the vicinity of Cape Lookout, N.C. Purse seine vessels from Beaufort, N.C., opportunistically harvest Atlantic thread herring for reduction from September to mid-October in the vicinity of Cape Lookout to Cape Fear. On average, migrating schools consisted of about 56 t of fish each, and ranged up to 204 t. Proximate analyses have shown that the protein content of Atlantic thread herring (20.65%; Hale, 1984) is slightly higher than Atlantic menhaden (14.50-17.02%; Dubrow et al., 1976), and fish oil yields from Atlantic thread herring in the fall are exceptional. Together both factors contribute substantially to fish factory production at a time when local abundance of Atlantic menhaden has temporarily waned. By mid-October, schools of *O. oglinum* migrated south of Cape Fear, N.C., and were unavailable to the purse seine vessels from Beaufort. Results of tagging studies (Pristas and Cheek, 1973) and coastal trawl surveys (Wenner and Sedberry, 1989) suggest *O. oglinum* overwinter off northern Florida.

Commercially exploitable schools of Atlantic thread herring are apparently not available in coastal waters (<3 miles from shore) north of Cape Hatteras. Presumably, the menhaden purse seine fleet from Virginia, with up to 20 vessels collectively making 7,000–9,000 sets per year in coastal waters of the Mid-Atlantic states (unpubl. data), would have occasional encounters with schools of Atlantic thread herring. Instead, catches of Atlantic thread herring by Virginia vessels are rare, especially in Chesapeake Bay (personal observ.), except as by-catch (Austin et al., 1994).

Relative to ageing Atlantic thread herring, agreement was good for paired age estimates using scale:otolith pairs, but the sample size was small. Scales of Atlantic thread herring are highly deciduous. After the catch was pumped from the purse seine into the hold of the carrying vessel, key scales from the midline below the dorsal fin on sampled fish were difficult to find. Specimens were often naked or contaminated with scales from other fish. Sagittal otoliths are, therefore, a more reliable tool for ageing Atlantic thread herring.

Owing to the brief time when Atlantic thread herring were available in purse seine catches, I was unable to properly validate sagittae as ageing structures for Atlantic thread herring. Nevertheless, Houde et al. (1983) judged the "alternating hyaline and opaque zones" on sagittae of *O. oglinum* from the west coast of Florida to be annual marks, while Arce and Sanchez (1991) used otoliths to age *O. oglinum* from Yucatan, Mexico.

Similar to the results of Houde et al. (1983), I found that the mean size of *O. oglinum* increased with estimated age, and that age 1 was the modal age group in the samples. Estimates of mean size at age 1 and 2 (155 and 172 mm, respectively) for fish from North Carolina were considerably larger than for specimens from the Gulf of Mexico (108.2 mm at age 1 and 152.4 mm at age 2; Houde et al., 1983), although results of both studies were in closer agreement for age 3 (Table 2). Using scales, Fuss et al. (1969) tentatively estimated that age 1 fish along the west coast of Florida averaged 146 mm FL, which is in close agreement with this study. Atlantic thread herring are moderately long-lived, and I estimated the age of two fish at ages 7 and 8. Houde et al. (1983) aged fish up to age 6, and Arce and Sanchez (1991) reported fish of age 8 in their samples.

Based on the gonads of adult fish, Hildebrand (1963) determined that Atlantic thread herring spawned off North Carolina in May and June, whereas, spawning in the eastern Gulf of Mexico was protracted from April through September (Houde, 1977). I collected recently spent female *O. oglinum* from a purse seine set near Cape Hatteras in early June; this tends to confirm spawning in spring off North Carolina. Later in the year, the gonads of adults collected in autumn were resting, which suggests that the fall migration south along the southeastern U.S. Atlantic coast is for the purpose of overwintering (Pristas and Cheek, 1973; Wenner and Sedberry, 1989).

Otolith analyses indicated that *O. oglinum* taken by cast nets in the vicinity of Beaufort during summer were almost exclusively young-of-the-year;

average size was 76 mm. From "a few measurements" in the Beaufort area, Hildebrand (1963) surmised that Atlantic thread herring attained a length of 35–60 mm at age 1 and 90–120 mm by the end of their second summer. Wenner and Sedberry (1989) probably portrayed a more accurate description of the growth of *O. oglinum* through age 1, based on modal distributions of fish collected during a quarterly trawl survey in coastal waters (to 9.1 m deep) from Cape Fear to Cape Canaveral. They suspected that fish 4–6 cm FL during summer were young-of-year; this group grew to a modal size of 8 cm FL by fall and winter. During the following spring age-1 fish ranged from 9 to 13 cm FL and age-2 fish ranged from 13 to 16 cm FL.

As Atlantic thread herring migrate south along the southeastern U.S. Atlantic coast in fall, they represent an abundant forage species for several coastal pelagic fishes. DeVane (1978) found Atlantic thread herring in 28% of the king mackerel, *Scomberomorus cavalla*, stomachs that he sampled in Onslow Bay, N.C. Studies along other areas of the U.S. coast have identified *O. oglinum* in the diets of bluefish, *Pomatomus saltatrix* (Wilk, 1977; Naughton and Saloman, 1984); crevalle jack, *Caranx hippos* (Saloman and Naughton, 1984); and Spanish mackerel, *S. maculatus* (Klima, 1959). When juvenile Atlantic thread herring leave estuarine waters along the central North Carolina coast in fall, bluefish and Spanish mackerel voraciously feed upon them in ocean inlet areas (personal observ.).

During the 1950's up to nine menhaden reduction plants in the southeastern Atlantic states were located at Morehead City, Beaufort, and Southport, N.C.; Younges Island, S.C.; and Fernandina Beach, Fla. (Vaughan and Smith, 1988); most of these plants probably processed *O. oglinum* during the fall fishing season. Only the Beaufort plant remains today, although factories in Southport and Fernandina Beach survived until the mid-1980's. Coastal U.S. regions are experiencing unprecedented population growth and waterfront properties have become more valuable for resort, marina, and condominium development, rather than traditional uses such as boat yards and fish houses (Houlahan, 1987). In this developmental climate, it would be exceptionally difficult to site a fish reduction plant in the coastal Carolinas, Georgia, or north Florida. Moreover, South Carolina prohibits purse seining within its state territorial sea. Thus, further exploitation of Atlantic thread herring along the southeastern U.S. Atlantic coast, beyond the reduction fishery in Beaufort during September and October, would presumably and necessarily be seasonal, and in the form of modest operations for bait whose catch could be utilized in crab and crayfish trap fisheries, or as bait and chum for hook-and-line fisheries.

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The Origin, Evolution, and Demise of the U.S. Sea Turtle Fisheries

W. N. WITZELL

"While I gazed on the large one, I thought of the soups the contents of its shell would have furnished for a 'Lord Mayor's dinner,' of the numerous eggs which its swollen body contained, and of the curious carriage which might be made of its shell,—a car in which Venus herself might sail over the Caribbean Sea, provided her tender doves lent their aid in drawing the divinity, and provided no shark or hurricane came to upset it."

— John James Audubon, 1832

Introduction

Fishing was America's first industry, and turtling played an important role in the nation's developing fisheries. However, before the European settlers arrived in the New World, Native Americans had already developed spiritual and gastronomic relationships with sea turtles. There are indications that ancient Florida tribes had eaten sea turtles and then placed the skulls in burial mounds (Johnson, 1952).

Sea turtle meat and eggs were also important foods for the early settlers long before turtle soup became a favorite of European royalty, and captive turtles expedited the exploration and colonization of the New World by providing larder for long sea voyages. Early explorers were particularly thankful for the turtles which ". . . often came as a Godsend in times of hunger and scurvy . . ." (Munroe, 1898).

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Turtling was undoubtedly one of the first commercial fisheries in the southeastern United States not only because sea turtles were abundant, but also because of the relative ease of capture when laying eggs on deserted beaches. Also, no boats, nets, or other expensive equipment were needed, and the turtles could be easily kept alive until sold.

The commercial fisheries for the now threatened and endangered species of sea turtles in U.S. waters have been neither adequately described nor analyzed in detail. Descriptive historical accounts of the southeastern regional sea turtle fishery were presented by True (1884, 1887), Schroeder (1924), and Ingle and Smith (1949), revised by Rebel (1974). Also, many detailed accounts of more localized sea turtle fisheries have also been published (Table 1). Many of these articles, particularly those written near the turn of the century, provide colorful commentary on the lives of early Americans. Additionally, for a brief period at the turn of the century, a San Diego, Calif., factory reportedly canned an estimated 1,000 green turtles per month (Cliffton et al., 1981). However, since those turtles were captured on Mexico's Baja peninsula, it is not considered here as a U.S. fishery.

Early commercial sea turtle landings data were collected sporadically and published in a series of U.S. Government fisheries documents from 1890 to 1930. From 1930 to 1974 sea turtle landings were routinely reported with all other commercially important fishery resources. In this paper, I describe the U.S. sea turtle fisheries and summarize the commercial sea turtle landings reported in Federal fishery documents for the continental United States, Puerto Rico, and Hawaii. These important baseline fisheries data on threatened and endangered species of sea turtles provide considerable insight into the sociology and economics of the U.S. sea turtle fishery. Additionally, these data also provide basic biological information, such as species composition, relative abundance, and temporal and spatial distributions. These factors are required to understand the ecology of

Table 1. — Published accounts of localized sea turtle fisheries.

Location	Citation
Florida	De Brahm (1764) *In* De Vorsey (1971) Audubon (1832) Smallwood (1842) *In* Tebeau (1981) Collins (1887) Murphy (1890, repr. 1987) Smith (1896) Brice (1898) Wilcox (1898) Carr and Caldwell (1956) Caldwell and Carr (1957) Ingle (1972) Ehrhart (1983) Witzell (1987)
Texas	Stevenson (1893) Hildebrand (1981) Doughty (1984)
Puerto Rico	Wilcox (1900, 1904)
Hawaii	Hendrickson (1969) Balazs (1980) Markrich (1983)

these unique reptiles and to enable resource managers to formulate sound management and conservation strategies, as mandated by the Endangered Species Act of 1973 and subsequent amendments. The entire historical data set was only recently assembled and published by Witzell (1994).

The Turtles

Five sea turtle species (Fig. 1) commonly frequent U.S. coastal waters: green, *Chelonia mydas*; loggerhead, *Caretta caretta*; Kemp's ridley, *Lepidochelys kempi*; hawksbill, *Eretmochelys imbricata*; and leatherback, *Dermochelys coriacea*.

Green Sea Turtle

The green is a large (90–136 kg) herbivorous turtle that primarily inhabits tropical waters. Juveniles, however, often frequent subtropical coastal bays and lagoons. Commercially, the green was the turtle of choice. The meat was flavorful, and the fatty tissue found under the shell, called calipee and calipash, was dried and used to make the turtle soup so popular with European royalty in the 18th and 19th centuries. The name "green turtle" refers to the color of this fat, not the shell. Because the green turtle could be carried alive for extended periods, some believe it may have provided the meat needed to enable early sailors to explore, colonize, and exploit the New World on their extended voyages (Parsons, 1962; King, 1981). Islands with large numbers of turtles, such as the Cayman Islands and Jamaica, became very important, and English, Spanish, and French fleets vied for control of these important victualling stations. The U.S population of green turtles in Florida is currently on the endangered species list.

Loggerhead Sea Turtle

The loggerhead, a large (90–180 kg) carnivorous turtle inhabiting subtropical and temperate coastal waters, is the most common sea turtle encountered in the southeastern United States (Thompson, 1988). The loggerhead was apparently less desirable because of its dark oily meat, although smaller loggerheads were reportedly more palatable (True, 1884; Munroe, 1898). True (1884) colorfully stated: "The flesh of the adult is leathery and oily, and smells very strongly of musk; it is, therefore, not generally eaten, although some pretend that they have partaken of it when fresh without nausea."

Loggerhead oil, while unfit for cooking because of its strong odor, was brushed on the bottoms of fishing vessels to prevent worm damage and used as a leather softener. Large turtles, in the early 1800's, were reportedly salted and fed to slaves in the West Indies (True, 1884). More recently, they were sold as "turtle balls" or "turtleburgers" to tourists in the United States (Caldwell and Carr, 1957). Although not the main target species, loggerheads became more important as greens became scarce, and they were probably taken whenever encountered. Loggerheads are currently listed as threatened.

Kemp's Ridley Sea Turtle

The Kemp's ridley is a small (36–45 kg) carnivorous turtle that primarily inhabits tropical, subtropical, and temperate coastal waters of the Gulf of Mexico and the U.S. Atlantic coast. The Kemp's ridley is unique in that the entire nesting aggregation emerges together from the sea to lay eggs during the day. Also, the species only nests at Rancho Nuevo in Tamaulipas, Mexico. The area was so remote that the nesting site was only discovered by scientists in 1961.

Although reportedly once the most abundant turtle in the Gulf of Mexico (Marquez-M., 1990), ridleys were not sought commercially (True, 1884), but the apparent distaste was not explained. However, although there are no ridley landings recorded, Caldwell and Carr (1957) reported the ridley to be almost as important as the green in the west Florida fishery and that it was not marketed but consumed locally. Today, because of historically intense egg exploitation and incidental captures in commercial fishing gear, the Kemp's ridley is the most endangered of all sea turtles.

Hawksbill Sea Turtle

The hawksbill is a small to medium (45–57 kg) carnivorous turtle inhabiting coastal tropical seas and has a fairly common distribution adjacent to tropical reefs. The hawksbill was not actively sought for food because, like the loggerhead, the flesh was dark, oily, and strong tasting. In fact, True (1884) stated that the hawksbill meat in the West Indies possessed distinct "cathartic qualities in a high degree." The hawksbill, however, was eagerly taken when encountered owing to its valuable "tortoise shell" used in the jewelry trade (Witzell, 1983). The very light, or "blond," shell was preferred, and a large hawksbill could provide 6–7 kg of shell (True, 1884). The worldwide exploitation of hawksbills for their shells hastened the decimation of this species.

Leatherback Sea Turtle

The leatherback is the largest (450–635 kg) sea turtle. This turtle nests on tropical Central and South American beaches and ranges along the Gulf and Atlantic coasts as far north as Canada. The leatherback is unique because it apparently feeds almost entirely on large pelagic jellyfish, and because it is able to maintain an internal temperature above ambient (Frair et al., 1972). The shell is soft and leathery and the meat is very oily and considered unpalatable. Consequently, the leatherback was never an important commercial species in the turtle fishery, although the eggs may have been collected and consumed locally in Puerto Rico.

Turtle Fishing Methods

The U.S. sea turtle fishery varied considerably and consisted of several directed and nondirected methods. Directed sea turtle fisheries consisted primarily of gill netting, seining, harpooning, diving, and turning—flipping turtles on their backs on the beach. Gill netting was the most common turtle fishing method. These special nets varied but were usually 60–80 m long, 4–5 m deep, with heavy 30 cm twine mesh, and were often set in shallow coastal channels and lagoons (Fig. 2, 3). These nets may have been actively fished by encircling an area suspected of containing turtles and then immediately retrieving them (runaround netting), or they may have been passively fished for sev-

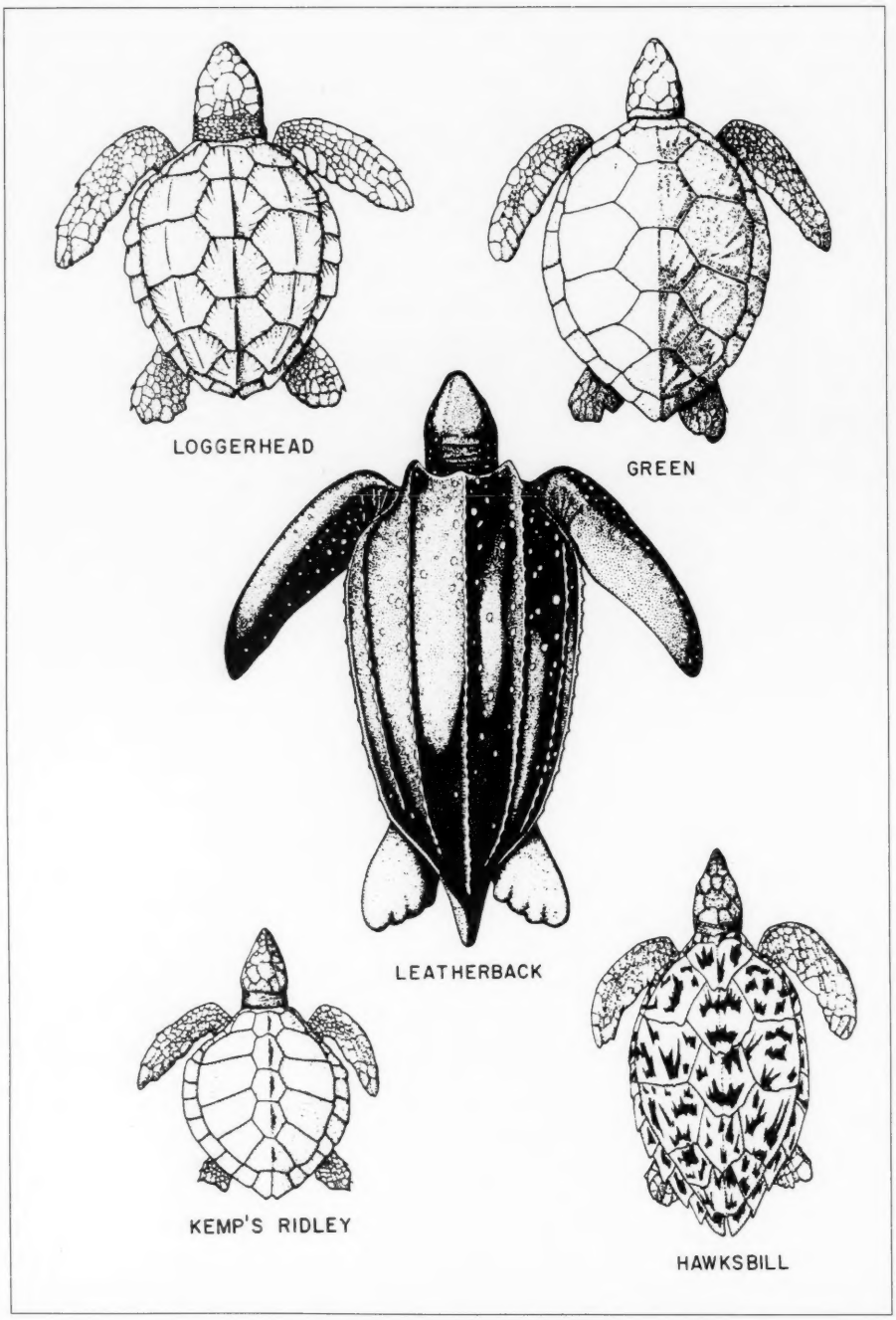

Figure 1. — The five sea turtle species commonly found in coastal U.S. waters.

Figure 2. — Turtle fishermen setting a typical turtle net. Photo courtesy of National Geographic Magazine.

eral hours (anchor or drift netting). Several passive nets were sometimes fished simultaneously by larger sailing vessels (Fig. 4).

The fishermen usually remained near the nets, sometimes for several days, and periodically removed struggling turtles before they drowned. True (1887) aptly described this as "the dullest of all fishing, and unending patience and considerable skill are required to make it successful." Wooden decoy turtles were often used to attract hawksbills to the nets in Puerto Rico (Wilcox, 1900, 1904). Seines typically had finer meshes than turtle gillnets, and they were either fished from two small boats in shallow water or fished directly off the beach using a small skiff to encircle the turtles (Fig. 5). In addition to turtles, these nets caught a wide variety of commercially important fin fishes.

Turtles captured alive in nets were preferred because they could be kept in pens (kraals) indefinitely until processing, usually canning or shipping alive on steamships to the New York, Philadelphia, and Baltimore fish markets (Fig. 6). Until shipment, the turtles were fed "turtle grass, sweet-potato vines, and sometimes morning-glory vines and mangrove leaves" (Wilcox, 1898). The net fisheries were historically localized in areas with turtle concentrations: Indian River Lagoon, Fla.; Lake Worth, Fla.; Key West, Fla.; Cedar Key-Crystal River, Fla.; and Aransas Bay, Tex.

Harpoons using detachable spearheads or "pegs" were sometimes used to capture turtles floating on the surface (Audubon, 1832). These "pegs," short steel barbs attached to a line, were designed to pierce the carapace but not to reach the turtle's vital organs and kill it. The peg, loosely fitted on a spear shaft and then plunged into the carapace, would then detach from the shaft and the line was used to haul in the turtle. Copulating turtles were particularly susceptible to harpoon fishing because of their apparent preoccupation with mating. Harpooned turtles were primarily for local consumption, and less frequently for commercial purposes because the harpooned turtles would eventually die of their wounds and spoil while awaiting shipment to northern markets. This method was most popular in the Caribbean.

Diving to capture turtles either by spear or by hand was a simple method that required little or no special equipment. The spear was either a length of wood or iron, depending on the available materials. This method was most effective on smaller specimens and was commonly used by native islanders for immediate local consumption. However, the more recent introduction of inexpensive snorkeling and scuba gear, complete with an entire arsenal of high-tech spear guns, has changed the nature

Figure 3. — An entangled green turtle being removed from the net. Photo courtesy of National Geographic Magazine.

of this fishery. Spear fishermen on tropical coral reefs have increased the harvest of juvenile turtles that were previously difficult to get, particularly the valuable hawksbill.

Additionally, to avoid injuring the turtle to keep it for live shipment, fishermen at the turn of the century devised a unique capture method by tying the boat painter to their leg and diving onto basking turtles (Fig. 7). True's (1887) caption for this figure reads "Diving for loggerhead turtle, Morehead City, North Carolina," but the animal is clearly a leatherback. The diver would seize the anterior edge of the carapace with one hand, the posterior with the other, and steer the turtle to the surface. This adventurous method was always exciting, but unfortunately sometimes dangerous. It was not unusual for fisherman to suffer lacerations, bruises, and even broken bones.

Turning female turtles on nesting beaches, particularly greens and hawksbills, occurred whenever possible. No special equipment was necessary and, like net-caught turtles, they could be held alive in kraals while awaiting sale. Historically this was probably the predominant harvesting method employed by fishermen around the world, and, combined with egg harvesting, contributed significantly to the rapid decline of sea turtle populations. However, there is no evidence that large numbers of loggerheads were turned, although they nested in considerable abundance along the U.S. southeast coast. This may have been due to their poor marketability.

Sea turtles were also captured incidentally by various commercial fishing gears: Haul seines, gill nets, and shrimp trawls in the southeastern and Gulf areas, and pound nets in the U.S. northeast and middle Atlantic areas. Although the turtle by-catch from these individual fisheries varied considerably, the total catch from all the fisheries combined was significant. Shrimp trawls were particularly successful at capturing sea turtles (Fig. 8). With the exceptions of some early directed gillnet fisheries (e.g. Texas and east central Florida), and the lingering fishery at Cedar Key, Fla., the U.S. commercial sea turtle fishery probably consisted mainly of turtles taken incidentally.

Some evidence suggests that sea turtle eggs were collected in considerable abundance whenever possible in the southeastern U.S. and Gulf of Mexico areas and were considered a delicacy. Eggs were collected by intercepting females nesting on the beach, butchering reproductive females captured by net or harpoon, and by probing nest sites with "a light stiff cane or a gun rod" (Audubon, 1832). Schroeder (1924) reported that there was a great demand for eggs, selling at $0.25/dozen, and Smith (1896) reported that loggerhead eggs in south Florida were harvested heavily by "fishermen and by predaceous animals, such as bears and raccoons, which walk the beach incessantly at night." Murphy (1890) reported that hunting turtles and eggs at Indian River, Fla., was dangerous because of the large numbers of bears foraging that were ". . . likely to display a pugnacious spirit . . ." if disturbed while eating turtle eggs.

The only turtle eggs recorded as commercial landings were for Monroe County, Fla., (Brice, 1898), where the 3,062 kg collected in 1895 were worth $810 (3,062 kg of eggs is equal to about 76,550 eggs at 40 g/egg). Neither the species nor the area of this egg harvest was given.

Turtle eggs were considered aphrodisiacs in some locations when eaten raw, but were probably better known for the moistness imparted to baked goods because the yolk did not solidify when cooked. True (1884) reported that green,

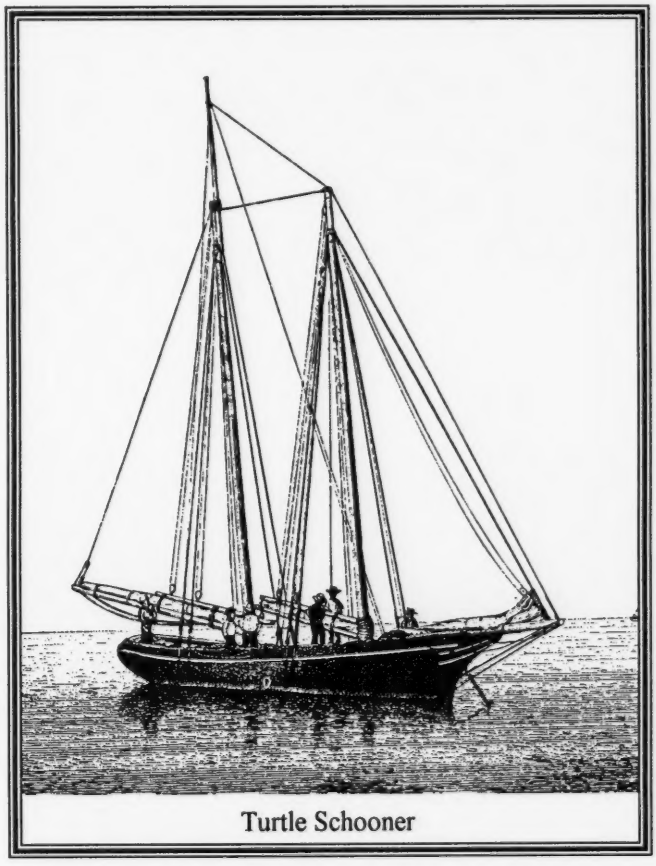

Figure 4. — A typical turtle schooner used throughout the southeastern U.S. and Caribbean (Collins, 1887).

Figure 5. — Successful turtle fishermen near Miami, Fla., who used a beach seine deployed by two skiffs. Photo from *Scene* magazine.

loggerhead, and hawksbill eggs were collected for the oil they produced that was "used in cookery and the arts." Consequently, although few egg harvest records exist, it appears that eggs from all sea turtles were frequently collected and used for local consumption. Additional summaries with information on the harvesting and exploitation of hawksbills, loggerheads, and Kemp's ridleys are reported by Witzell (1983), Dodd (1988), and Marquez (1994), respectively.

The Turtle Fisheries

Landings Data

The landings and values reported in this paper are from U.S. Government fisheries publications. The earliest material, generally titled "Fishery Industries of the U.S.," was incorporated in the annual reports of the U.S. Commissioner of Fisheries from 1873 to 1939. These early reports described the coastal marine resources and fisheries reported by the fledgling U.S. Fish Commission (USFC), originally an independent agency. In 1903 the USFC was renamed the Bureau of Fisheries under the Department of Commerce and Labor and remained in the Department of Commerce after 1911. The Bureau was placed under the Department of the Interior in 1939, and finally became the National Marine Fisheries Service (NMFS) under the Department of Commerce in 1970. Reports after 1939 dealt mostly with fisheries statistics. These publications, titled "Fishery Statistics of the U.S.", were produced by the Division of Statistics for the years 1940 to 1977, and summarized all of the individual states' detailed landings into a single volume. Turtle data, however, ended shortly after passage of the Endangered Species Act of 1973.

The U.S. Fish Commission/Bureau of Fisheries reports did not differentiate between turtle species from 1897 to 1930, and those landings data were lumped in the category "turtles," except for terrapins. The "turtle" data for that period were edited to avoid substantial landings of freshwater snapping and softshell turtles by using only those turtle landings reported from coastal counties with gill nets and trawls. Consequently, some sea turtle data were undoubtedly lost, particularly in the northeastern United States and on Florida's east coast. In 1930, the "turtles" category was split into loggerhead, green, hawksbill, snapping, and softshell turtle categories. However, from what we presently know about the distribution and abundance of sea turtles, the BCF/NMFS port agents responsible for the collection of landing statistics were probably unable to accurately identify sea turtle species, and there is a likelihood that many of the earlier identifications were incorrect. For instance, from 1942 to 1978, the "hawksbill turtle" illustration in the statistical pictorial section of the "Fishery Statistics of the United States" is clearly a Kemp's ridley turtle.

Commercial sea turtle landings data were originally collected by interviews with fishermen and later directly from dockside seafood dealers. Unfortunately, there may have been some reluctance to report accurate landings in the late 1800's because the fishermen and seafood dealers may have been suspicious of government officials (Doughty, 1984). It is probable that many additional turtles were landed and directly consumed by vessel crews and not officially recorded, particularly the less marketable loggerheads and ridleys. Therefore, while these figures should be considered minimum harvest estimates, they do reflect trends in the fishery. Also, the Kemp's ridley, or "bastard" turtle as it was called in the 1800's, seems to have fallen through the statistical cracks. Although recognized as a species of little importance in the Gulf of Mexico by True (1884), it is likely that ridleys were landed as either greens, hawksbills, or "sea turtle," or were consumed locally. All weights in this pa-

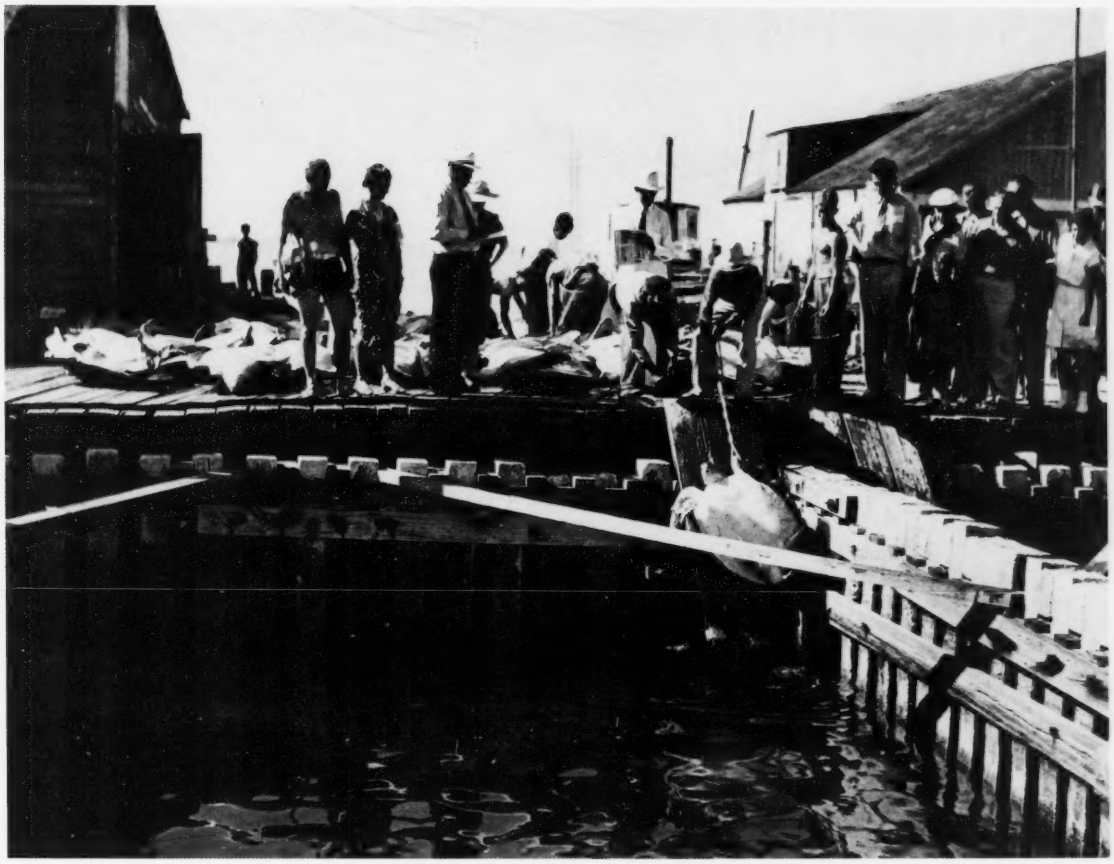

Figure 6. — The famous turtle "kraals" of Key West, Fla. Photo courtesy of National Geographic Magazine.

per have been converted from pounds to kilograms.

Total sea turtle landings were considerable (Fig. 9), and they often contributed significantly to rural coastal fishing communities, both culturally and economically. Turtles were taken along their entire U.S. coastal range and undoubtedly provided local sustenance at an affordable price. Landings averaged near 10,000 kg, with obvious peaks at the turn of the century and at 1970, just prior to passage of the Endangered Species Act. The low during 1943 is possibly related to World War II, and the intensive German U-Boat offensive in the western Atlantic.

Sea turtle prices averaged $0.10/kg from the turn of the century to the end of World War II, $0.20–0.30/kg through the 1950's, and then steadily rose to about $0.50/kg in 1975 (Fig. 10). Although sea turtles may have commanded big prices in the New England and European fish markets, the average price to fishermen seems pitifully low by today's standards. Many of the following comments, particularly those regarding turtle landings by county, by gear, and by month are supported by the data documented in Witzell (1994).

The Northeast Fishery

Sea turtle landings have been reported from Massachusetts, Rhode Island, New York, New Jersey, Virginia, and North Carolina. Landings were limited and resulted primarily as by-catch from the pound-net fishery. Most were loggerheads, although the data indicated that some greens and hawksbills were taken. Current life history data indicates that these species identifications were probably incorrect, and the turtles were undoubtedly Kemp's ridleys, which frequent these waters every summer (Lazell, 1980; Morreale et al., 1992).

New Jersey and Virginia were the major sea turtle producing states in the northeast (Fig. 11, 12) but, because they were mostly loggerheads, their value was negligible. New Jersey and Virginia turtle landings were recorded from several counties, with Monmouth and Northampton being the largest producers, respectively. Many of these states still have active pound-net fisheries, and

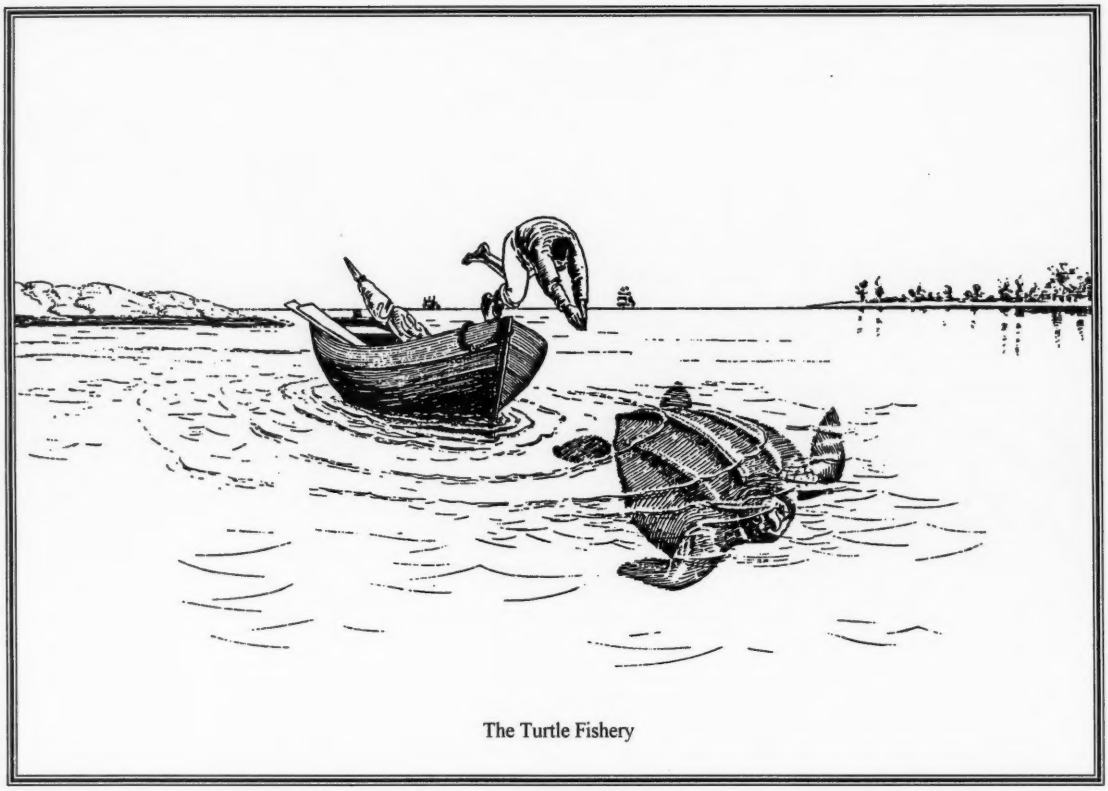

Figure 7. — Diving on basking sea turtles was an effective, but sometimes hazardous, method of capturing live turtles (True, 1887).

sea turtles are still incidentally captured in considerable numbers (Lutcavage and Musick, 1985; Burke et al., 1994).

The Southeast Fishery

Florida

The commercial sea turtle fishery was flourishing throughout Florida by 1890 (Fig. 13). The green turtle was originally the main target species, but there were also considerable landings of loggerheads as the greens became scarce in Florida waters. Landings were recorded from all months, but May and September were the most important. Gill nets (anchor, drift, and run-around) were the predominant gear for greens, while shrimp trawls were predominant for the loggerheads; Monroe and Levy counties were the largest sea turtle producers. The Levy County turtle fishery (Cedar Key) lasted the longest in Florida and consisted of locally caught greens and unrecorded Kemp's ridleys. The green turtle landings from Monroe County were originally from turtles captured in the Florida Keys. However, as the turtles became scarce in the early 1900's, large sailing schooners fished in Costa Rican and Nicaraguan waters and landed the turtles at Key West, Fla. By 1920, Key West turtle landings were predominantly imports (Rebel, 1974). A pictorial account of this colorful and exotic fishery is presented by Duncan (1943). Sometimes, according to Caldwell and Carr (1957), the schooners would stop at Grand Cayman to allow the turtles to fatten in large kraals before returning to Key West.

The Key West turtle kraals were established in the 1800's to facilitate live shipment of turtles to northern markets (Fig. 6). Early descriptions of the construction and operation of these kraals were detailed by Park (1912) and Schroeder (1924). The turtles were roped around the flipper, pulled out of the kraal, usually by a swimmer, and assembled on the dock for live shipment or canning. If they were to be shipped by steamer to New York, the flippers were often pierced and tied together with rope and the animals stored on their backs in the shade. Turtles stored "right-side up" suffocated because the weight of the animal on the lungs prevented them from breathing.

A small cannery was started in 1896, and the turtles to be slaughtered were lined up on the dock and the heads and flippers quickly removed with an axe. The plastron was cut off, and the meat was then removed, cleaned in seawater, hung on hooks overnight, and

Figure 8. — Loggerhead turtles captured in NMFS shrimp trawls in the ship channel at Cape Canaveral, Fla. Photo by L. Ogren.

canned into soup the following day. However, this was apparently not the classical gelatinous soup made from the calipee (Schroeder, 1924), but some concoction of meat and broth.

Louisiana

Louisiana turtle landings were fairly substantial, staying at or near 1,000 kg per year (Fig. 14), and showed a sharp rise in price from 1960 to 1975. These turtles were primarily by-catch from the shrimp fleet and were recorded as mostly greens with a few loggerheads. However, from what we currently know about the ecology and distributions of sea turtles in the northern Gulf of Mexico, these "green" turtles were undoubtedly ridleys, the most common species in Louisiana inshore waters (Viosca, 1961; Hildebrand, 1981). Confusion about which sea turtle species were landed (green or ridley) probably resulted from the fact that the local name for ridley turtles is "white sea turtle", a name sometimes given to green turtles because of their white plastron. These turtles were frequently caught in shrimp trawls and taken home and eaten (Liner, 1954; Gunter, 1981). Landings were recorded year round from Jefferson, Orleans, Plaquemines, St. Barnard, and St. Mary parishes with most of these turtles being landed in April in Jefferson Parish.

Texas

The Texas green turtle fishery at the turn of the century did not last very long, but it was extremely intense (Fig. 15). The magnitude of the landings in such a short time-span quickly depleted the local stocks. Gill nets (anchor and drift) and haul seines were the most commonly used gears in seven Texas counties, with Aransas and Nueces being the most important. Turtle kraals and canning factories appeared near Corpus Christi, Tex., in the mid-1800's (Hildebrand, 1981; Doughty, 1984). Live turtles were shipped by schooner to New York or by steamship to New Orleans, although some turtles were canned as meat or soup and shipped elsewhere for consumption. These canneries also packed oysters, fish, game, and beef. Production, however, was interrupted by a devastating hurricane, the Civil War, and a yellow fever epidemic before starting up again in 1872. The last cannery at Fulton operated until 1896, when the lack of turtles forced operations to move to Tampico, Mexico.

Puerto Rico

The commercial turtle fishery in Puerto Rico was neither extensive nor intense, consisting of greens and hawksbills (Fig. 16). The landings data indicate that the fishery did not gain financial importance until just before the U.S. Endangered Species Act was passed in 1973. The fishery had, up until that point, been artisanal, capturing the turtles with reef-fish gill nets, spears,

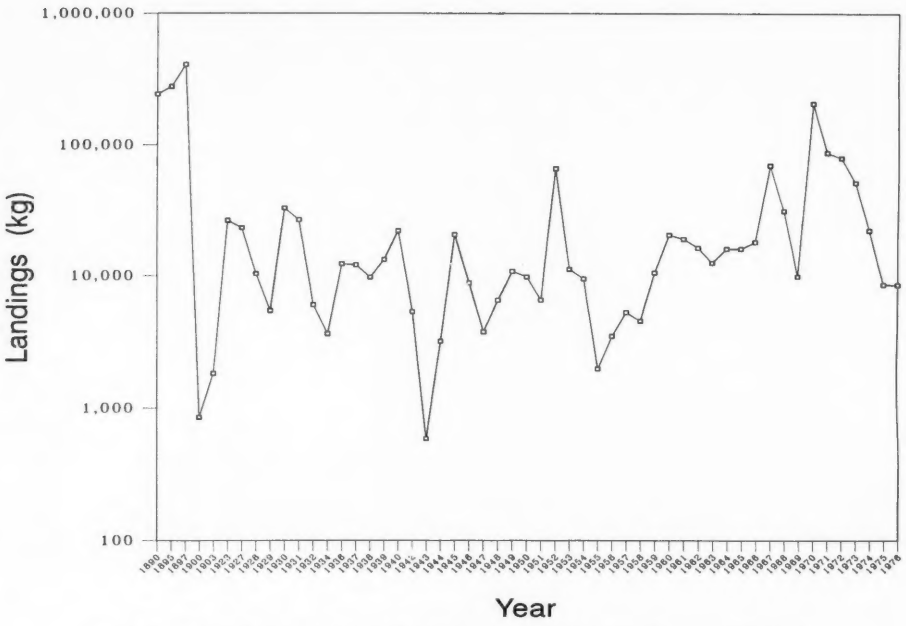

Figure 9. — The total commercial catch of sea turtles by year, all areas and all species combined.

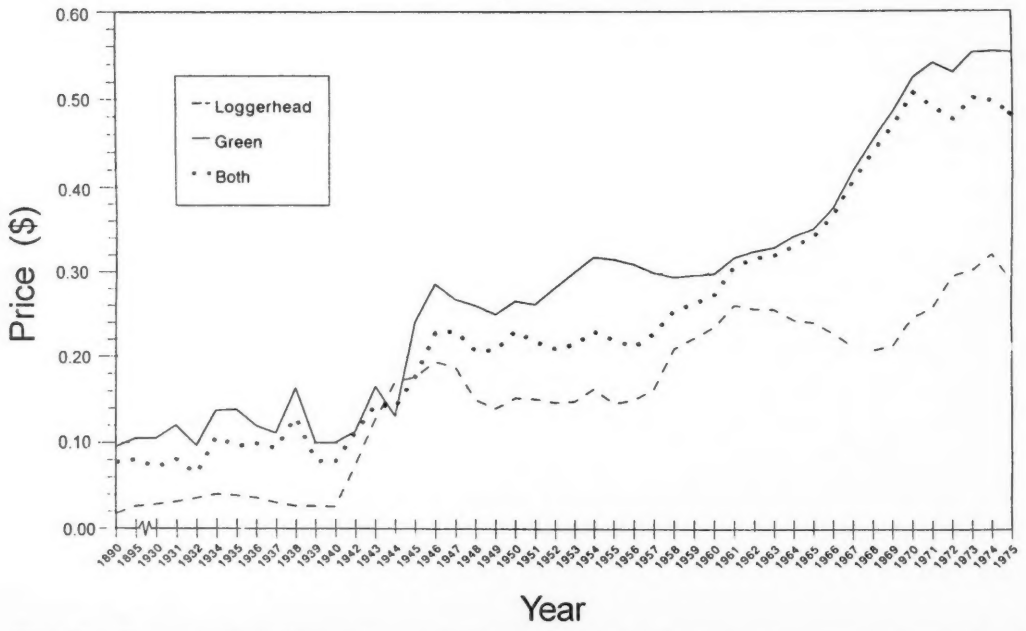

Figure 10. — The average price per kilogram of loggerhead and green sea turtles. A 5-point moving average was used to smooth the graph.

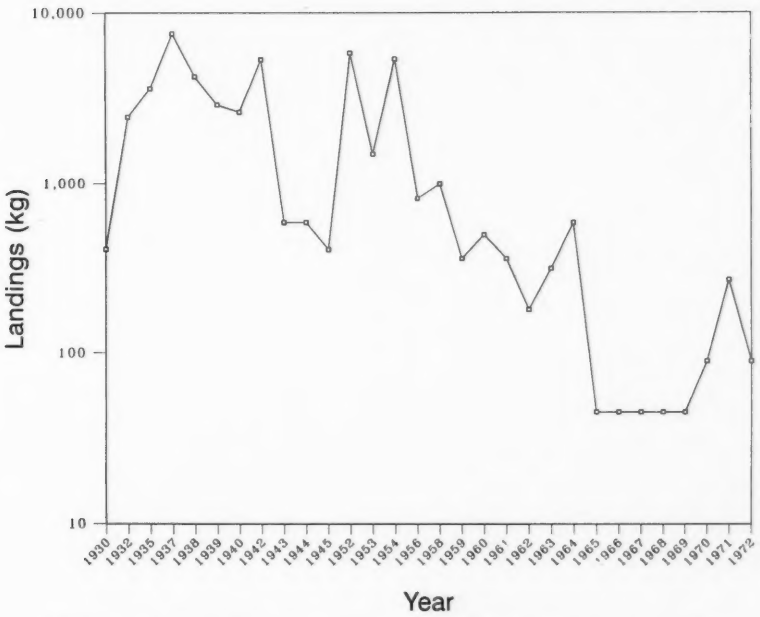

Figure 11 . — Reported New Jersey commercial sea turtle landings (all species combined).

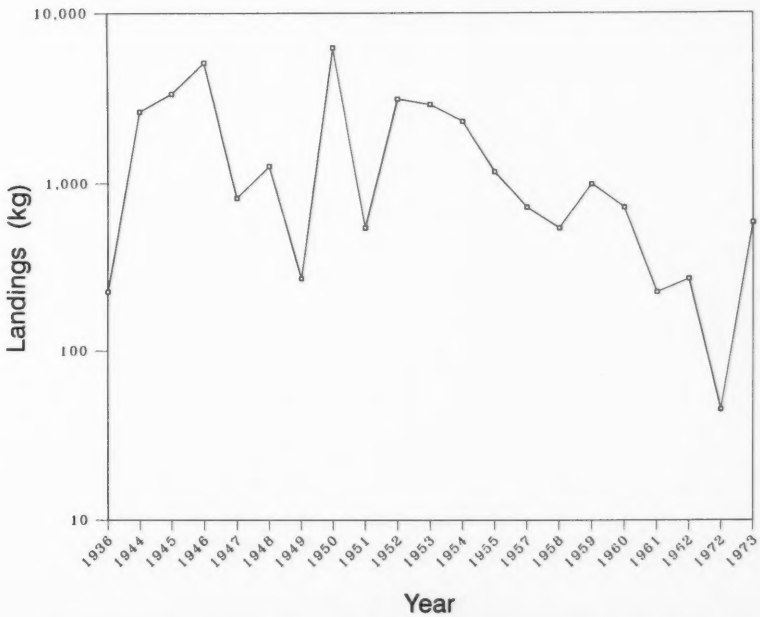

Figure 12. — Reported Virginia commercial sea turtle landings (all species combined).

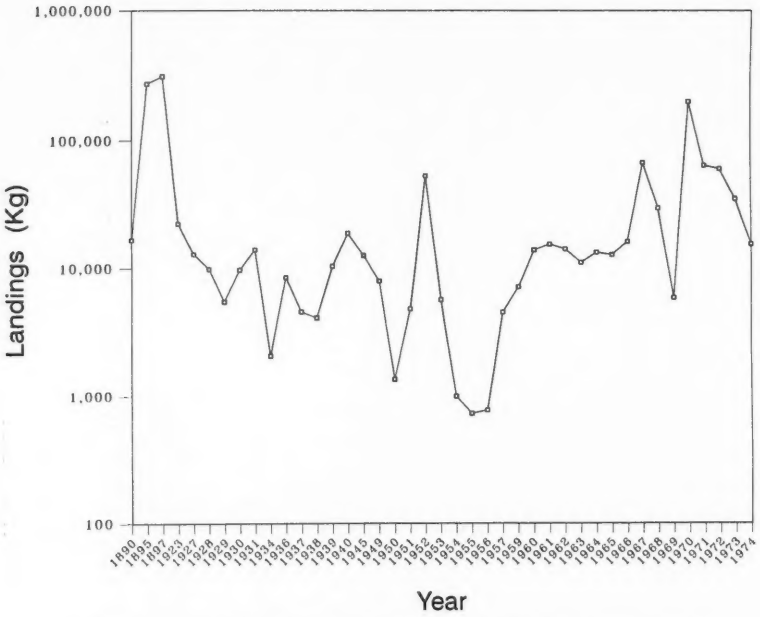

Figure 13. — Reported Florida commercial sea turtle landings (all species combined).

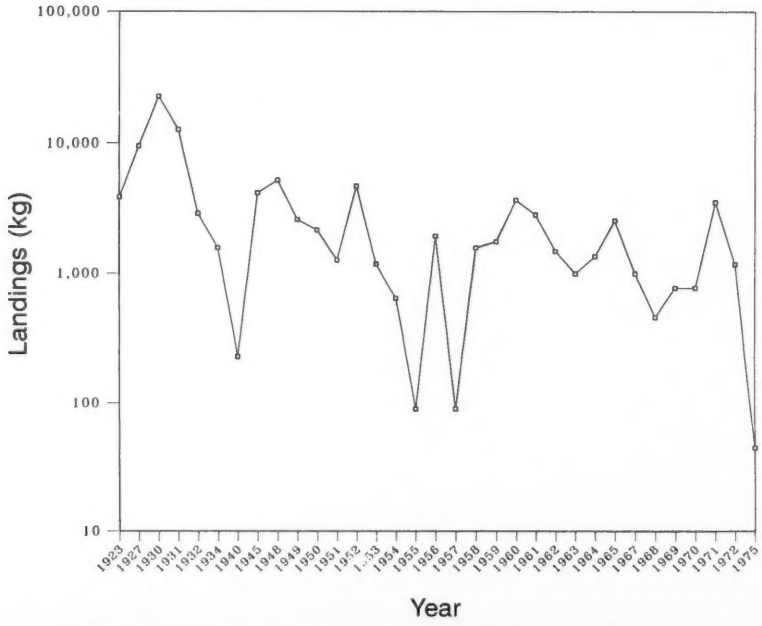

Figure 14. — Reported Louisiana commercial sea turtle landings (all species combined).

and by hand while diving. These turtles were usually butchered and sold to villagers on the beach. Unfortunately, commercial fishery landings data of local catches were not reported in detail by the NMFS until 1971. The south and west coasts were the most important turtling districts.

The Hawaiian Fishery

The Hawaiian turtle fishery was also artisanal, but, unlike Puerto Rico, it eventually achieved considerably more commercial importance (Fig. 17). Green sea turtles were most frequently landed, and they were taken with an impressive array of methods ranging from gill nets (anchor and drift), seines (haul and common), spears, traps, miscellaneous undetermined gear, and by hand. Early on, sea turtles played an important role in Hawaiian cultural history and were depicted in native song and dance (Markrich, 1983). Turtles were also an important source of protein for Polynesians since at least 600 A.D., and Native Hawaiians would capture then alive and hold them in special fish ponds until needed. Turtle landings were reported year round from the five main Hawaiian Islands, but Maui was the most important island and September and October were the most important months.

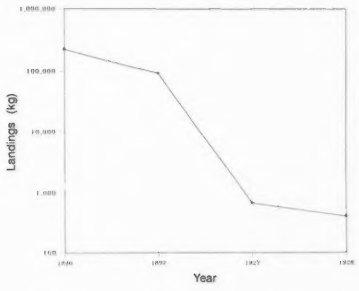

Figure 15. — Reported Texas commercial sea turtle landings (all species combined).

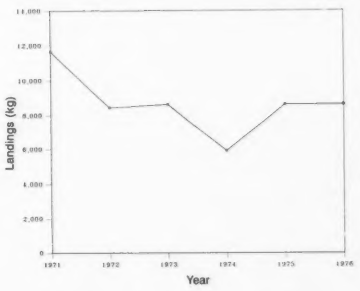

Figure 16. — Reported Puerto Rico commercial sea turtle landings (all species combined).

Fishery Declines

Sea turtles are slow growing, long-lived animals that reach sexual maturity between 15 and 50 years (National Research Council, 1990). They are extremely difficult to manage, particularly as a sustainable resource. A stage-based population model for loggerheads indicated that rapid declines in subadults would adversely impact the population to a greater extent than would a similar decline in eggs and small juveniles (Crouse et al., 1987). Unfortunately, it was these large juvenile turtles that were often commercially harvested (Table 2) because the directed turtle fisheries frequently concentrated on those turtles readily captured in lagoonal areas (e.g. Mosquito Lagoon, Fla., and Aransas

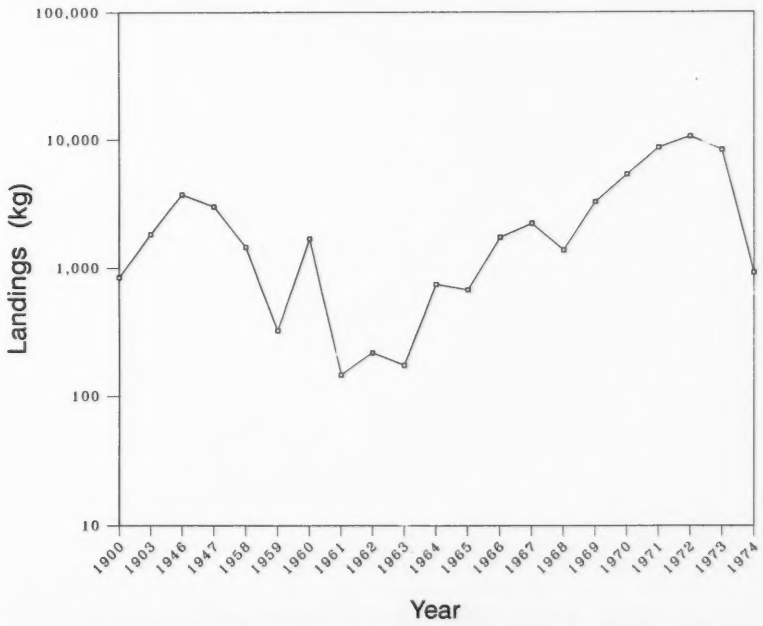

Figure 17. — Reported Hawaii commercial sea turtle landings (all species combined).

Table 2. — Average weights[1] of commercially caught sea turtles.

Species	Location	Weight (kg)	Citation
Green	Beaufort, N.C.	4	True (1884, 1887)
Green	Charleston, S.C.	2-7	True (1884, 1887)
Green	St Augustine, Fla.	9-11	True (1884, 1887)
Green	Halifax River, Fla.	16	True (1884, 1887)
Green	Indian River, Fla.	23-27	True (1884, 1887)
Green	Indian River, Fla.	16-23	Wilcox (1898)
Green	Cedar Keys, Fla.	272-363	True (1884, 1887)
Green	Crystal River-Cedar Keys, Fla.	20	Ingle (1972)
Green	Key West, Fla.	18-45	True (1884, 1887)
Green	Biscayne Bay, Fla.		Smith (1896)
	Inside	11	
	Outside	27-34	
Green	Aransas Bay, Tex.	122	Stevenson (1893)
Green	Hawaii	7	Cobb (1905)
		14-45	Hendrickson (1969)
Loggerhead	Beaufort, N.C.	23	True (1884, 1887)
Loggerhead	Biscayne Bay, Fla.	136	Smith (1896)
Hawksbill	Mona Island, P.R.	11-34	Wilcox (1904)

[1] Weights were converted from pounds to the nearest kilogram.

and Matagorda Bays, Tex.). These lagoons appear to be important developmental habitats for green, loggerhead, and Kemp's ridley turtles (Ehrhart, 1983), and it is not surprising that harvests exceeded recruitment and that these slow growing populations were rapidly depleted.

Additionally, not only were these juvenile turtles readily available, they may have been more valuable than adult turtles when captured far from distant northeastern markets with no transportation readily available (Audubon, 1832; Collins, 1887; Schroeder, 1924). This is because very large turtles were undoubtedly more difficult to handle, transport, and keep alive than smaller turtles. Audubon (1832) found that "the smaller the turtle, the dearer they were, and I could have purchased one of the loggerhead kind that weighed more than seven hundred pounds for little more money than another of thirty pounds." Apparently these very large turtles soon spoiled without refrigeration or ice unless quickly consumed. Several smaller turtles could be kept alive and enjoyed one at a time.

The decline, however, was attributed to several reasons. The Texas canneries experienced sharp declines in turtle supplies by 1895, that were attributed to the capture of nesting females in Central America. Thus, Texas enacted minimum weight and closed season regulations in 1895. Smith (1896) noted that the green turtles in Biscayne Bay, Fla., had already disappeared because of intense fishing pressure from Bahamian sailing vessels, and he suggested that protective measures be passed to save them from extermination.

The disappearance of juveniles from Florida waters was also noticed by Munroe (1898), who believed that this was not due to excessive fishing pressure, but to the gradual captures of adult females that nested on Bahamian and Central American shores. He suggested that a captive breeding and hatchery program was necessary or, failing that, the importation of eggs from foreign rookeries. Brice (1898) reiterated Munroe's opinions, but went even further by suggesting that nesting females and eggs should be left undisturbed and that there should be a legal minimum weight in order to protect the commercially important subadults.

The turtle fishery in Indian River, Fla., had declined since 1886 (Wilcox, 1898), and that was attributed to the increased presence of steamboats, which supposedly frightened off the turtles, and to a 1894–95 cold-stunning event. Egg harvesting was blamed for the overall decline in turtle abundance in Florida by Townsend (1900), who also believed that these eggs should be protected and never harvested. The Texas green turtle fishery decline in the later 1800's was blamed on a combination of overfishing, jettying of the lagoonal passes, and the severe freeze of 1894–95 (Hildebrand, 1981).

Whatever the reasons, it was obvious that the U.S. commercial sea turtle fishery was in serious trouble by 1900, and would remain so. With the exception of the small targeted fishery at Cedar Key, Fla., the fishery existed almost entirely as by-catch in other, more important, fisheries.

Summary, Current Status, and Outlook

Commercial fisheries, habitat destruction, and pollution has had a devastating impact on both U.S. and world sea turtle populations. The U.S. Endangered Species Act of 1973 and subsequent amendments has provided the legislation needed to prevent the extinction of these magnificent animals in the northwestern Atlantic Ocean. The NMFS Southeast Fisheries Science Center (SEFSC) is presently conducting research to determine growth, migration, and developmental habitats of sea turtles in the southeastern United States. The SEFSC is also developing methods to mitigate the incidental turtle catch in commercial trawl and pelagic longline fisheries. The turtle excluder device (TED) was developed by the SEFSC to reduce the capture of turtles in shrimp trawls, and is constantly being modified to operate effectively in different trawl fisheries under various conditions. These TED's are now being developed for use in most Latin American countries and in the some Indo-Pacific countries.

International conservation efforts are aimed at preventing the extinction of sea turtles and helping populations to recover. Sea turtle recovery plans have been developed and are now being implemented, and the NMFS is responsible for research and management of sea turtle populations in U.S. waters. In spite of these efforts, however, it is unlikely that there will ever be another turtle fishery for any sea turtle species in the United States.

Acknowledgments

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Seasonal Occurrence of the White Shark, *Carcharodon carcharias*, in Waters off the Florida West Coast, with Notes on its Life History

DOUGLAS H. ADAMS, MICHAEL E. MITCHELL, and GLENN R. PARSONS

Introduction

The white shark, *Carcharodon carcharias*, is typically found in cold and warm-temperate waters throughout the world, although occurrences in tropical waters have been documented (Compagno, 1984). In the western North Atlantic Ocean, the species is most commonly encountered in continental shelf waters from Cape Cod to Cape Hatteras (Casey and Pratt, 1985). The white shark is considered rare south of Cape Hatteras and in the Gulf of Mexico (Castro, 1983), although the species is encountered by both commercial and recreational fishermen in these regions.

White sharks caught by commercial longline vessels operating in Florida waters are often sold in a small but lucrative market, primarily for their jaws. The high value of white shark jaws and meat has encouraged "erratic spot fisheries" in New York, California, South Africa, and South Australia (Compagno, 1990). Commercial longline fishermen and seafood dealers on Florida's west coast report that demand for white shark jaws has increased since the late 1980's. The jaws from white sharks collected in Florida waters can sell for up to several thousand dollars in unprepared condition for a large, high-quality set, while fully prepared jaws may yield double that price[1]. A similar market for targeted and incidentally caught white sharks in California waters prompted recent legislation (California Assembly Bill 522, effective 1 January 1994) which restricts landings to prevent white sharks from becoming overfished by commercial and recreational fisheries.

Due to its apparent rarity or low encounter rate in the Gulf of Mexico, very little biological data has been published on the white shark from this region, and verified records are scarce. In this study we will 1) review historical reports of the occurrence of the white shark off the west coast of Florida, 2) include recent verified records from this area, 3) present evidence of seasonal (winter/spring) occurrence in the region, and 4) provide selected life-history data.

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ABSTRACT—The white shark, Carcharodon carcharias, *is considered rare in the Gulf of Mexico; however, recent longline captures coupled with historical landings information suggest that the species occurs seasonally (winter-spring) within this region. We examined a total of seven adult and juvenile white sharks (185–472 cm total length) captured in waters off the west coast of Florida. Commercial longline fisheries were monitored for white sharks during all months (1981–94), but this species was captured only from January to April. All white sharks were captured in continental shelf waters from 37 to 222 km off the west coast of Florida when sea surface temperatures ranged from 18.7° to 21.6°C. Depths at capture locations ranged from 20 to 164 m. Fishing gear typically used in Gulf of Mexico offshore fisheries may not be effective at capturing this species, and the apparent rarity of white sharks in this area may be, in part, a function of gear bias.*

Methods and Materials

All white shark specimens examined were captured by commercial fishermen with bottom longline gear designed specifically for targeting coastal-pelagic sharks or grouper/snapper species. The bottom longline fishing gear used off Florida's west coast has evolved since the early 1980's. Initially, the bottom longline fishery in Florida's west coast waters targeted grouper/snapper species and consisted of 4–10 km long stainless steel mainlines with 600–1,500 hooks attached to the mainline with approximately 2 m long monofilament gangions. In the current longline fishery targeting sharks off the west coast of Florida, longline gear typically consists of 8–24 km monofilament (or to a lesser degree, stainless steel) mainlines with approximately 2 m long monofilament gangions.

Total length (TL), fork length (FL), and precaudal length (PCL) of each specimen were recorded according to Compagno (1984). In this paper, total lengths are used unless otherwise specified. Total weights were taken when possible or were estimated according to Mollet and Cailliet (1993). State of maturity was determined by macroscopic examination of the reproductive tract, clasper condition, or by published size-at-maturity estimates (Bigelow and Schroeder, 1953; Casey and Pratt, 1985;

[1]G. Hubbell, 150 Buttonwood Dr., Key Biscayne, FL 33149. Personal commun.

Pratt, 1993). Testes from one specimen were examined histologically, and clasper length was measured on all males.

For age determination, vertebrae were removed from the area below the origin of the first dorsal fin on several of the specimens, and vertebral centrum diameters were measured to the nearest millimeter. Determination of vertebral growth bands and age were estimated according to Cailliet et al. (1985) and Parsons (1985). Sea surface temperature (SST) data for continental shelf waters off the west coast of Florida were obtained from the National Oceanic and Atmospheric Administration (NOAA) Oceanographic Monthly Summary series from January 1984 to April 1994.

Results

We examined seven white sharks (three males and four females) captured by commercial fishermen off the west coast of Florida from 1986 through 1994 (Table 1). Although we solicited specimens during all seasons between late 1981 and early 1994, white sharks were collected only during winter and spring months (February and March 1986, April 1987, April 1993, January and February 1994). Mean monthly SST of continental shelf waters off the west coast of Florida from January 1984 to April 1994 ranged from 15.7° to 31.0°C, although white sharks were only collected in this region during periods when water temperatures were 18.7° to 21.6°C (Fig. 1). Locations of capture extended from waters off Clearwater, Fla. (lat. 27°58'N), southward to Cape Sable, Fla. (lat. 25°00'N), and ranged from 37 to 222 km offshore. Depths at capture locations ranged from 20 to 164 m.

The three male sharks collected were 185, 275, and 472 cm long and had a clasper index (clasper length/total length × 100) of 3.5, 14.4, and 10.4%, respectively. We histologically sectioned the testes of the 275 cm shark and observed fully developed spermatozoa. Additionally, a large quantity of spermatophores were collected from the seminal vesicles, sectioned, and found to contain low densities of mature spermatozoa. The claspers of the largest (472 cm) shark were 49 cm long and were fully calcified. The smallest specimen (185 cm) had undeveloped testes, uncalcified claspers, and was immature.

The four female sharks were 267, 277, 359, and 391 cm long. The ovary of the immature 277 cm shark contained developing ova. Prominent, partially healed scars were observed above the insertion of the left pectoral fin of the 391 cm female (Fig. 2). These scars cut through the dermal layer and slightly into the muscle tissue. The wound

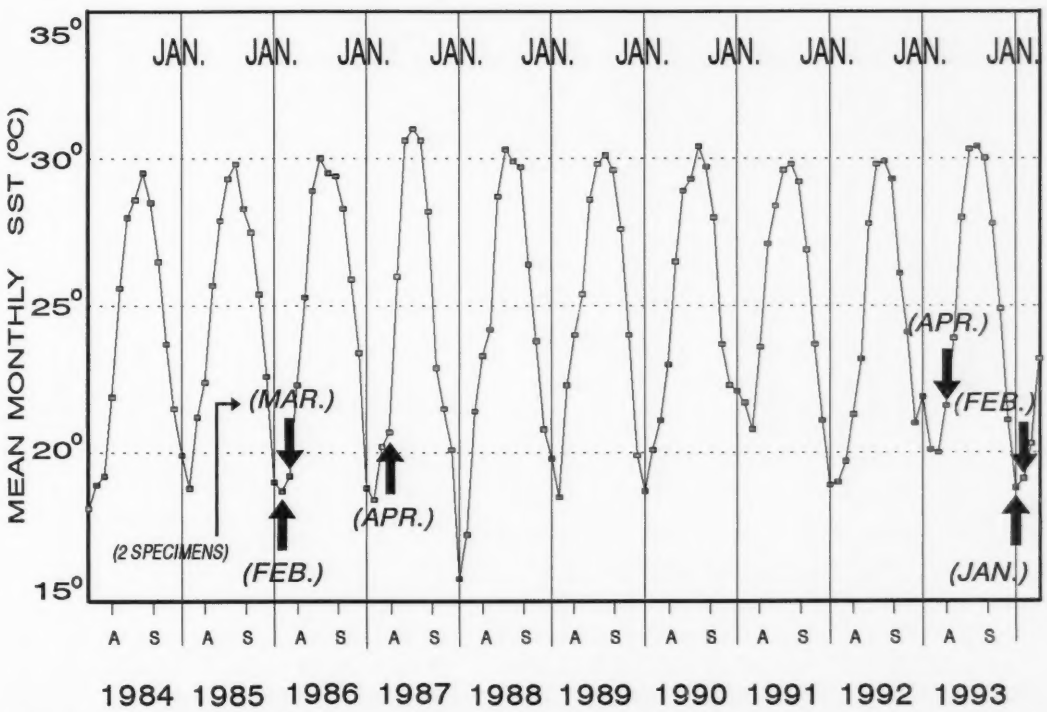

Figure 1. — Mean monthly sea-surface temperatures (SST) for shelf waters off the central west coast of Florida for January 1984 through April 1994 (from NOAA's Oceanographic Monthly Summary series). Vertical lines designate the month of January in each year. Arrows indicate months when white sharks were captured in the study area.

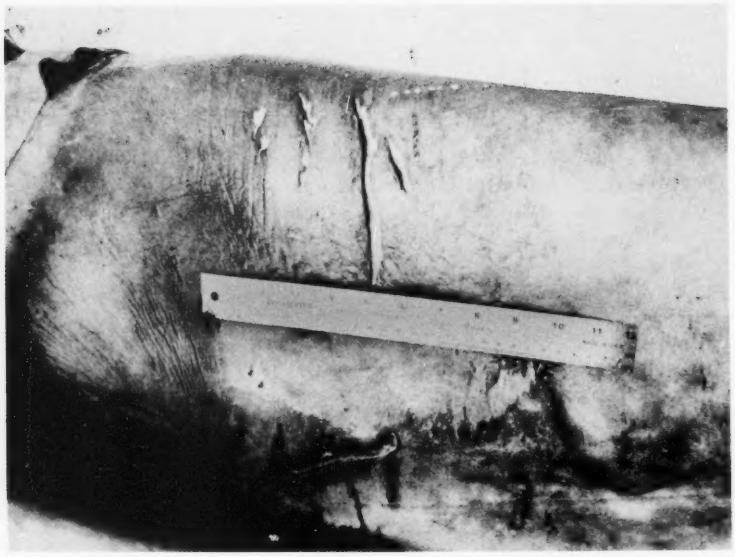

Figure 2. — Lateral view of the partially healed scars above the insertion of the left pectoral fin of the 391 cm TL female white shark. The left edge of the photo shows two posterior gill slits.

shape, orientation, and spacing between parallel punctures, as well as the vertically orientated lacerations, suggested that the wound was caused by a conspecific. The placement of these scars and the similarity to mating scars found on females of other shark species suggest they may have occurred during mating; however, the reproductive behavior of this species is poorly known. Similar scars have been documented on white sharks in South Australian waters, but due to the frequency of bite marks observed on both immature and mature individuals in the area, they could not be confirmed as evidence of mating activity (Bruce, 1992).

Vertebrae were removed from the 277 cm and 391 cm specimens. Six growth bands were counted on vertebrae from the smaller shark (centrum diameter = 31 mm) and ten from the larger specimen (centrum diameter = 53 mm). These values agree closely with those of similar size white sharks examined by Cailliet et al. (1985), but currently no validation information is available to determine the periodicity of these growth zones.

The stomach of the 472 cm male shark contained the remains of a requiem shark, *Carcharhinus* sp. (probably *C. plumbeus*), estimated to be 180 cm long. The stomach of the 391 cm female contained the entire remains (in two sections) of a dolphin (Delphinidae) estimated at 150 cm long. Two of the white shark specimens were eviscerated at sea, so their stomachs could not be examined. The three other stomachs that could be examined were empty, but not everted.

We collected three species of parasitic copepods from the 275 cm male shark and the 391 cm female shark. *Pandarus smithii* and *P. satyrus* were present in the mouth of the male shark, and *Dinamoura latifolia* specimens were attached to the trailing edge of its caudal fin. *Pandarus satyrus* was also collected from the mouth and left pectoral fin of the female.

Table 1.—Biological and capture data for white sharks collected from waters off the west coast of Florida, 1986–1994.

Capture date	Sex	Length (cm) TL	FL	PCL	Clasper length (cm)	Weight (kg)	Approx. capture location	Capture depth (m)	Maturity
28 Feb. 1986	F	267	236	208		145[1]	27°20'N 83°27'W	60	Immature
9 Mar. 1986	M	275	263	236	39.5	220.4	27°25'N 84°30'W	162	Mature
Mar. 1986	M	185	170	147	6.4	49.9	27°58'N 83°45'W	57	Immature
13 Apr. 1987	F	277	227	218		167[1]	26°58'N 83°50'W	73	Immature
28 Apr. 1993[2]	F	359	335			498.9	25°00'N 84°15'W	164	Immature
3 Jan. 1994	M	472	440	397	49	998[1]	27°58'N 83°19'W	20	Mature
22 Feb. 1994	F	391	355	321		536[1]	26°54'N 84°12'W	119	Mature

[1] Estimated weight using equation from Mollet and Cailliet (1993).
[2] Shark was cut in thirds before being landed and was put together when measured; weight represents eviscerated weight.

Discussion

The earliest documented white shark report from the west coast of Florida was a female, estimated to be 457 cm, collected with a set line during the winter of 1937–38 off Sarasota (Springer, 1939). A 472 cm specimen was collected with a set line approximately 13 km off Englewood on 1 February 1939 (Springer, 1939). Another specimen, measuring 444 cm, was caught 30–64 km off Sarasota at a depth of 30 m in early 1943 (Clark and Von Schmidt, 1965). On 10 February 1965, a 360 cm female white shark was captured in a net intended to catch bottlenose dolphins, *Tursiops truncatus*, at Mullet Key, near St. Petersburg (Moe and Martin, 1965). A 332 cm female white shark was caught off Sarasota on 21 January 1966 (Cape Haze Marine Laboratory, 1966). On 19 February 1967, a 338 cm male, reportedly mature and weighing 480 kg, was captured on a shark longline 5.6 km west of Midnight Pass, Sarasota (Cape Haze Marine Laboratory, 1967).

Bigelow and Schroeder (1953) estimated that white sharks mature at approximately 366–427 cm. A more recent

estimate indicates that males mature at 360 cm (Pratt, 1993). Four of the seven white sharks examined in this study were immature. The size of the 472 cm male shark and its 49 cm fully calcified claspers indicate that this specimen was mature. The length of the claspers, the presence of mature spermatozoa in the testes, and the presence of spermatophores suggest that the 275 cm male shark examined in this study was mature or maturing. The 391 cm female shark was eviscerated at sea, and therefore no gonads were available to determine state of maturity. However, the total length and presence of possible mating scars on this specimen indicated maturity.

Other large and presumably mature white sharks have been documented in the Florida Keys and waters to the south of peninsular Florida. Among these was a white shark reported to measure 640 cm and to weigh 3,324 kg that was collected approximately 260 km south of Florida near Cojimar, Cuba, in 1945 (Bigelow and Schroeder, 1948). The size of this specimen was later refuted by Randall (1987). A confirmed visual account of a white shark measuring approximately 400 cm was reported on 1 January 1960 off Grassy Key, Fla. (Nelson, 1969). More recently, two white sharks were captured off the Florida Keys: a 206 kg specimen captured in 1988 (Ellis and McCosker, 1991) and a 405 cm, 451 kg specimen landed by rod and reel from a depth of 152 m approximately 30 km off Marathon, Fla., in January 1989.

National Marine Fisheries Service observers reported 35 white sharks as by-catch in the Japanese longline tuna fishery from February through April 1979 in the Gulf of Mexico (Rivas and McClellan, 1982), although no specific information was available. In a study of white shark distribution in the western North Atlantic, Casey and Pratt (1985) compiled 17 reports and sightings of white sharks throughout the Gulf of Mexico. Of these 17 observations, 11 were reported during the months of January, February, and March.

All specimens examined in our study were captured off the west coast of Florida between the months of January and April; all other confirmed sightings and many of the unconfirmed sightings of white sharks in this area were made during this same time period. Longline fishing effort in Florida's west coast waters during 1986–90 was typically lowest during the colder winter and early spring months when compared to fishing effort during the rest of the year[2]. Although fishing effort was reduced during the winter and early spring months, white sharks were principally observed during these periods and not during the warmer months when fishing effort was highest.

The occurrence of this species may be correlated with water temperature (Compagno, 1984; Casey and Pratt, 1985). Sea surface temperatures at the time and location of white shark captures in our study ranged between 18.7° and 21.6°C. In western Atlantic waters to the north, primarily between Cape Cod, Mass., and Cape Hatteras, N.C., white sharks occurred in water temperatures ranging from 11° to 24°C, although 75% of the occurrences in this region were when surface temperatures were from 15° to 22°C (Casey and Pratt, 1985). Similar water temperature ranges (maximum temperatures ≤26°C) for white sharks were recorded in waters near the Farallon Islands, Calif. (Ainley et al., 1981; Ainley et al., 1985), Natal, South Africa (Compagno, 1984; Cliff et al., 1989), and South Australia (Bruce, 1992).

The fact that white sharks captured in our study were taken when longline fishing effort was the lowest and when sea-surface temperatures were the lowest, suggest that white sharks move into the Gulf of Mexico or into Florida shelf waters during the winter and early spring months when water temperatures drop below 22°C. Unconfirmed sightings of white sharks in the Gulf of Mexico during the summer months may be misidentifications. We have examined mako sharks, *Isurus* spp., that were misidentified as small white sharks by Florida fishermen (Personal observ., G. Parsons and D. Adams), and other sharks found in the western North Atlantic have also been misidentified by fishermen as white sharks (Casey and Pratt, 1985).

Although water temperature may influence the distribution of white sharks (Compagno, 1984; Casey and Pratt, 1985), prey availability may also influence the apparent seasonal occurrence of this species off the west coast of Florida. In coastal waters off central California, inshore/offshore movements of white sharks were related to seasonal abundances of pinniped prey species (Ainley et al., 1985). Marine mammals, both dead and alive, are thought to be an important food source for white sharks throughout their range (Arnold, 1972; Pratt et al., 1982; Castro, 1983; Casey and Pratt, 1985; Long, 1991; and others). Marine mammal mortalities in Gulf of Mexico waters, as indicated by stranding records, are highest during winter and spring months (Wells et al., 1980; Jones, 1987; Weigle et al., 1991). Dolphins in Gulf of Mexico waters have had shark-bite scars on as many as 22% of specimens observed (Jones, 1987; Wells[3]). Movements of dolphins out of estuarine and bay habitats and into coastal waters during winter and spring have also been documented (Wells et al., 1980; Scott et al., 1990). Increased abundance of marine mammals, marine mammal carcasses, and other prey off the west coast of Florida during these periods may provide a seasonally abundant food source for white sharks.

Principal methods used to capture white sharks in the northwestern Atlantic were longline gear, rod and reel, and harpoon (Casey and Pratt, 1985). Commercial longline gear is the primary gear used in the Gulf of Mexico which is capable of capturing this species. Four of the seven specimens examined in this study and many of the historical specimens reported from the west coast of Florida were tangled in longline gear and were not actually captured by terminal hooks. Commercial longline fisheries in Florida typically use monofila-

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[3]R. Wells, Chicago Zoological Society, Sarasota Dolphin Research Program, c/o Mote Marine Laboratory, 1600 Thompson Parkway, Sarasota, FL 34236. Personal commun.

ment gangions, which are routinely severed by large sharks (Berkeley and Campos, 1988). Thus, commercial fishing gear commonly used in west-coast Florida waters may not be effective in capturing white sharks, and the apparent rarity of white sharks in the Gulf of Mexico may be, in part, a function of gear biases. In addition, the results of this study suggest that the occurrence of white sharks is seasonal in this region and that their distribution/availability is limited by water temperature, food resources, or other factors.

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The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, the *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 12, "A List of Common and Scientific Names of Fishes from the United States and Canada," fourth edition, 1980. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

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Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

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Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

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All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8 × 10 inches, sharply focused glossies of strong contrast. Potential cover photos are welcome, but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

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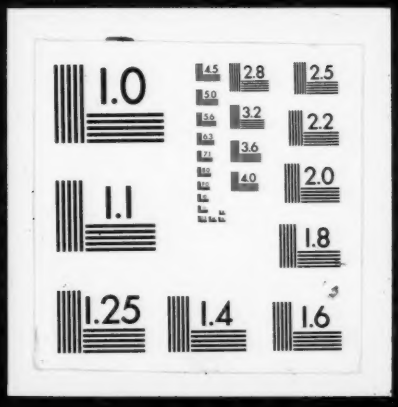
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